The Global Ocean Observing System

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Essential Ocean Variable Specification Sheet

Ocean Sound

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EOV Specification Sheet curated by:

Biology and Ecosystems Panel

DETAILED INFORMATION ON HOW TO READ THE SPECIFICATION SHEET CAN BE FOUND IN THIS GUIDE

The Ocean Sound EOV has a full implementation plan, which can be found here.

Background and justification

Sound travels exceptionally well in the ocean, making it a powerful and cost-effective tool for observing marine environments over vast spatial and temporal scales. Ocean sound monitoring provides essential insights into biodiversity, ecosystem health, human activity, and environmental change—supporting science, policy, and industry needs.
The Ocean Sound Essential Ocean Variable (EOV) enables the collection of standardised acoustic observations globally. It allows us to assess how different sources of sound (from natural events to anthropogenic noise such as shipping, construction, or seismic surveys) contribute to changing soundscapes and affect marine ecosystems.
Many marine species rely on sound for communication, navigation, and reproduction. Increasing ocean noise disrupts these functions, with observed impacts on fisheries, animal distributions, and ecosystem services.
Sound is a non-invasive, scalable, and cost-efficient method for monitoring the ocean. Passive acoustic monitoring can detect and track marine life, human activities, and physical processes (e.g., ice break-up or seismic events) without the need for expensive, labor-intensive field campaigns. This presents significant savings for governments, industries, and research programs seeking to monitor large and remote ocean areas.
Climate change is also transforming underwater soundscapes. Reductions in sea ice, ocean warming, shifting species distributions, and ocean acidification—all alter sound production, propagation, and detection.
The Ocean Sound EOV supports international goals for biodiversity conservation, climate adaptation, and sustainable ocean use. Its implementation provides decision-makers with actionable, long-term data at lower cost and with broader coverage than many traditional methods, contributing directly to global observing systems and ocean governance frameworks.

Integration with Global Observation Frameworks

The Global Climate Observing System (GCOS) developed the Essential Climate Variable (ECV) framework to define necessary observations for monitoring Earth's climate (Bojinski et al., 2014). Some EOVs, including ocean physics, biogeochemistry, and biology/ecosystems variables (GCOS, 2022a; GCOS, 2022b), are also ECVs.

The Essential Biodiversity Variables (EBVs) defined and curated by the Group on Earth Observations Biodiversity Observation Network (GEO BON) complement the GOOS biological and ecosystem (BioEco) EOVs (Miloslavich et al., 2018; Muller-Karger et al., 2018; Bax et al., 2019). The EOVs represent the basic observations of a particular parameter or process. EBVs are time series of biodiversity observations across genes, species populations, communities, or ecosystems. Thus, EOVs may be seen as the building blocks for GEO BON. The EOVs can be used to synthesise the EBVs as time series of BioEco EOV sub-variables at one location, or as time series of gridded, mapped, or modelled EOVs (Jetz et al., 2019).

The GOOS Biology and Ecosystems Panel collaborates with the Physics and Climate and Biogeochemistry Panels to advance EOVs, advocating for the need for biological observations, information management, and applications. GOOS, MBON, GEO BON, and OBIS work together to standardise guidelines and data management for EOVs, EBVs, and ECVs.

Current observing networks and coordination

Diverse networks and communities are collecting observations of biology and ecosystems EOVs at different scales and in different regions. An initial baseline survey conducted in 2019/20 identified 203 active, long-term (>5 years) observing programs systematically sampling marine life. These programs spanned about 7% of the ocean surface area, mostly concentrated in coastal regions of the United States, Canada, Europe, and Australia (Satterthwaite et al 2021). This information can be found in the GOOS BioEco Metadata Portal, which is continually updated. To consult the latest information, please visit: https://bioeco.goosocean.org

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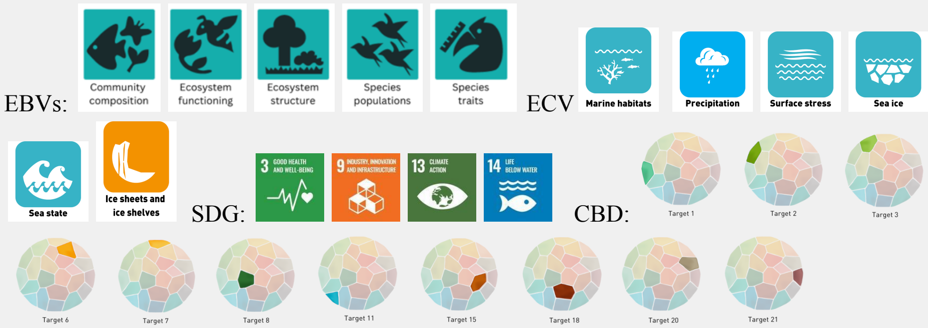

1. EOV information

ESSENTIAL OCEAN VARIABLE (EOV)	Ocean Sound
DEFINITION	Use of sound to estimate physical properties, biological processes, and human activities in the ocean
EOV SUB-VARIABLES - key measurements that are used to estimate the EOV ***bare minimum**	Sound pressure*
	Particle motion (displacement, velocity, acceleration)
SUPPORTING VARIABLES - other measurements that are useful to provide scale or context to the sub-variables of the EOV	Environmental: sea state, sea ice, subsurface temperature, subsurface salinity, subsurface currents, ocean bottom pressure, bathymetry, sediment.
	EOV related: - Sources: non-acoustic information on distribution of sound sources (e.g. ship AIS data); acoustic characteristics of anthropogenic, abiotic and biotic sources - Receivers: sensitivity and directionality of acoustic sensor as a function of frequency
DERIVED PRODUCTS - outputs calculated from the EOV and sub-variables, often in combination with the supporting variables	Sound field and trends, ambient noise levels, statistical distribution of sound pressure levels as a function of frequency, soundscape (characterisation of the sound field including identification of sources - anthropogenic, abiotic and biotic), distribution of sound sources in space and time, biodiversity indicators, acoustic indices (see ISO standard 18405)

2. Phenomena to observe - what we want to observe with this EOV

This section presents examples of priority phenomena for GOOS that can be (partly) characterised by this EOV's sub-variables. This list is not exhaustive but serves to provide general guidance on how observation efforts can structure their planning and implementation The GOOS application area(s) the phenomena are relevant for are depicted as follows icons: Climate , ocean health , operational services

PHENOMENA TO OBSERVE		Acoustic events: e.g. earthquake, animal call, ice calving, boat noise, rain/wind, storm	Cyclical/temporal patterns of ambient sound and soundscape analysis;	Detection of sound-producing organisms to estimate their abundance, distributions, and migrations	Acoustic Indices
PHENOMENA EXTENT	HORIZONTAL	local, regional or global (~ 1 m to 10s of km)	local, regional or global (~ 1 m to 10s of km)	local, regional or global (~ 1 m to 10s of km)	
	VERTICAL	surface, subsurface, upper ocean, deeper ocean	surface, subsurface, upper ocean, deeper ocean	surface, subsurface, upper ocean, deeper ocean	
	TEMPORAL	Milliseconds (e.g. animal call) to hours (e.g. wind)	daily to annually	daily to annually	annually to many decades
RESOLUTION TO OBSERVE PHENOMENA	HORIZONTAL	local, regional or global (~ 1 m, e.g. animal call, to 10s of km, e.g. earthquake)	local, regional or global (~ 1 m to 10s of km)	local, regional or global (~ 1 m to 10s of km)	local, regional or global 10s to 1000s of km
	VERTICAL	surface, subsurface, upper ocean, deeper ocean	surface, subsurface, upper ocean, deeper ocean	surface, subsurface, upper ocean, deeper ocean	surface, subsurface, upper ocean, midwater, deeper ocean
	TEMPORAL	Milliseconds (e.g. animal call) to hours (e.g. wind)	daily to pluri-annually	daily to pluri-annually	annually to many decades

SIGNAL TO CAPTURE	- Sound levels: in pressure (dB re 1 µPa) or in particle displacement (dB re 1 pm), velocity (dB re 1 nm s^{-1}), or acceleration (dB re 1 µm s^{-2}) - Mean square spectral density: sound pressure (dB re 1 µPa^2/Hz), or in particle displacement (dB re 1 pm^2/Hz), velocity (dB re 1 $(nm/s)^2$/Hz, or acceleration dB re 1 $(um/s^2)^2$/Hz	- 10% or gradual change in sound levels: in pressure (dB re 1 µPa) or in particle displacement (dB re 1 pm), velocity (dB re 1 nm s^{-1}), or acceleration (dB re 1 µm s^{-2}) - 10% or gradual change in mean square spectral density: sound pressure (dB re 1 µPa^2/Hz), or in particle displacement (dB re 1 pm^2/Hz), velocity (dB re 1 $(nm/s)^2$/Hz, or acceleration dB re 1 $(um/s^2)^2$/Hz	- 10% change in sound levels: in pressure (dB re 1 µPa) or in particle displacement (dB re 1 pm), velocity (dB re 1 nm s^{-1}), or acceleration (dB re 1 µm s^{-2}) - 10% change in mean square spectral density: sound pressure (dB re 1 µPa^2/Hz), or in particle displacement (dB re 1 pm^2/Hz), velocity (dB re 1 $(nm/s)^2$/Hz, or acceleration dB re 1 $(um/s^2)^2$/Hz	
SUB-VARIABLES NEEDED TO MEASURE	Sound pressure p(t) Particle motion (displacement, velocity, acceleration)	Sound pressure p(t) Particle motion (displacement, velocity, acceleration)	Sound pressure p(t) Particle motion (displacement, velocity, acceleration)	Sound pressure p(t)
SUPPORTING VARIABLES NEEDED	Acoustic characteristics and metadata of relevant sound sources, sound propagation	Tidal and lunar information, depth, temperature, pH, species composition	Acoustic characteristics of relevant sound sources, sound propagation, tidal and lunar information, depth, temperature, pH, species composition	Acoustic characteristics and metadata of relevant sound sources, sound propagation

3. GOOS Observing Specifications or Requirements

This section outlines ideal measurements for an optimal observing system for this Essential Ocean Variable (EOV). It offers guidance on creating a long-term system to observe key phenomena related to the EOV. These values are not mandatory, and no single system is expected to meet all requirements. Instead, the combined efforts of various observing systems should aim to meet these goals. Observations at different scales are also valuable contributions to global ocean observation if shared openly.

EOV	Ocean sound

PHENOMENA	**#1 Acoustic events**		
EOV SUB-VARIABLE	Sound pressure p(t)	**DEFINITION**	Variation in pressure caused by a sound wave, relative to the ambient atmospheric pressure in a medium. It is measured as the root-mean-square (RMS) or instantaneous pressure of a sound wave. Sound Pressure Level (abbreviation: SPL, symbol: L_p) is the level in decibels for a time-averaged (RMS) sound pressure p with respect to a reference pressure p_0 is defined as 20 $\log_{10}(p/p_0)$. The SI unit for pressure is the Pascal (Pa) and the underwater reference pressure is 1 μPa.

	Resolution			Timeliness	Uncertainty Measurement	Stability	Sampling approach	References
	Spatial Horizontal	**Spatial Vertical**	**Temporal**					
IDEAL	Depends on source. Array of multiple calibrated sensors regularly	Depends on source. Array of multiple calibrate d	Depending on source, could be as short as millisecond (e.g. snapping	Dependent on sources and applications.R eal time for acoustic event detection in	Depends on hydrophone specifications (~ ± 1 dB)		Autonomous or cabled hydrophone recording at the minimum sampling rate to encompass the full spectrum of the source (i.e. source dependent, minimum	Erbe, C., Duncan, A., Hawkins, L., Terhune, J.M., Thomas, J.A. (2022). Introduction to Acoustic Terminology and Signal Processing. In: Erbe, C., Thomas, J.A. (eds)

	placed over entire ensonified area (horizontally). Can also be towed.	sensors regularly placed over the entire ensonified area depths	shrimp snap) to hours (e.g. chronic boat noise)	case of foreseeable consequences (e.g. illegal fishing boat in MPAs, earthquake, illegal dynamite fishing, etc.). Other applications are independent on time.			double the peak frequency of the source to avoid aliasing).	Exploring Animal Behavior Through Sound: Volume 1. Springer, Cham. https://doi.org/10.1007/978-3-030-97540-1_4 Robinson, S.P.; Lepper, P. A. and Hazelwood, R.A. (2014) Good Practice Guide for Underwater Noise Measurement. Teddington, England, National Measurement Office, Marine Scotland, The Crown Estate, 95pp. (NPL Good Practice Guide No. 133). DOI: http://dx.doi.org/10.25607/OBP-21 Geel, N. C. F. van, Risch, D., & Wittich, A. (2022). A brief overview of current approaches for underwater sound analysis and reporting. Marine Pollution Bulletin, 178, 113610. doi:10.1016/j.marpolbul.2022.113610 Madhusudhana, S. et al. (2022). Choosing Equipment for Animal Bioacoustic Research. In: Erbe, C., Thomas, J.A. (eds) Exploring Animal Behavior Through Sound: Volume 1. Springer, Cham. https://doi.org/10.1007/978-3-030-97540-1_2
DESIRABLE	Depends on source. Several (2 - 3) calibrated sensors to estimate propagation loss over an area. Can also be towed.	Depends on source. Several calibrated sensors to estimate propagation loss over depth	Depending on source, could be as short as millisecond (e.g. snapping shrimp snap) to hours (e.g. chronic boat noise)	1 day - 1 month	Depends on hydrophone specifications (~ ± 1 dB)			
MINIMUM	Depends on source. Local (single calibrated sensor fixed location).	Depends on source. Local (single calibrated sensor fixed depth)	Depending on source, could be as short as millisecond (e.g. snapping shrimp snap) to hours (e.g. chronic boat noise)	6 months	Depends on hydrophone specifications (~ ± 3 dB)			

								Lucke, K., MacGillivray, A. O., Halvorsen, M. B., Ainslie, M. A., Zeddies, D. G., & Sisneros, J. A. (2024). Recommendations on bioacoustical metrics relevant for regulating exposure to anthropogenic underwater sound. The Journal of the Acoustical Society of America, 156(4), 2508–2526. doi:10.1121/10.0028586 ISO (2017). 18405, " Underwater acoustics—Terminology" (International Organization for Standardization, Geneva, Switzerland), p. 51.

EOV SUB-VARIABLE	Particle motion (displacement, velocity, acceleration)					DEFINITION		Sound particle motion refers to the oscillatory motion of particles in a medium caused by the propagation of a sound wave. This motion is distinct from the sound pressure, as it describes the physical movement of the particles in response to the wave's energy. Sound particle motion can be expressed in terms of displacement, velocity, and acceleration.	
	Resolution					Uncertainty		Sampling approach	References
	Spatial Horizontal	Spatial Vertical	Temporal	Timeliness	Measurement	Stability			
IDEAL	Depends on source. Array of multiple calibrated sensors regularly placed over entire ensonified area.	Depends on source. Array of multiple calibrate d sensors regularly placed over the entire ensonifie d depths	Depending on source, could be as short as millisecond (e.g. snapping shrimp snap) to hours (e.g. chronic boat noise)	Dependent on sources and applications. Real time for acoustic event detection. Other applications are independent on time.	Depends on sensor specifications (~ ± 1 dB)			Autonomous or cabled particle motion sensor (e.g. vector sensor) recording at the minimum sampling rate to encompass the full spectrum of the source (i.e. source dependent, minimum double the peak frequency of the source to avoid aliasing). By convention in underwater acoustics, the z axis is usually chosen to point vertically down from the sea surface, with x and y axes in	Nedelec, S. L., Campbell, J., Radford, A. N., Simpson, S. D., & Merchant, N. D. (2016). Particle motion: the missing link in underwater acoustic ecology. *Methods in Ecology and Evolution*, 7(7), 836–842. doi:10.1111/2041-210X.12544 Nedelec, S.L., Ainslie, M.A., Andersson, M.H., Cheong S-H., Halvorsen, M.B., Linné, M., Martin, B., Nöjd, A., Robinson, S., Simpson, S.D., Wang, L. and Ward, J. (2021) Best Practice Guide for Underwater Particle Motion Measurement for Biological Applications. Exeter, UK. University of Exeter for the IOGP Marine Sound and Life Joint Industry Programme, 89pp. & Appendices. DOI: http://dx.doi.org/10.25607/OBP-1726 ISO (2017). 18405, " Underwater acoustics—Terminology" (International Organization for
DESIRABLE	Depends on source. Can use several calibrated sensors to estimate propagation loss over a larger area	Depends on source. Several calibrate d sensors to estimate propagati on loss over depths.	Depending on source, could be as short as millisecond (e.g. snapping shrimp snap) to hours (e.g. chronic boat noise)	1 day - 1 month	Depends on sensor specifications (~ ± 1 dB)				

MINIMUM	Depends on source. Local (single calibrated sensor at fixed location)	Depends on source. Local (single calibrated sensor fixed depth)	Depending on source, could be as short as millisecond (e.g. snapping shrimp snap) to hours (e.g. chronic boat noise)	6 months	Depends on sensor specifications (~ ± 3 dB)		the horizontal plane.	Standardization, Geneva, Switzerland), p. 51.

PHENOMENA	**#2 Cyclical/temporal patterns of ambient sound and soundscape analysis AND** **#3 Detection of sound-producing organisms to estimate their abundance, distributions, and migrations**

EOV SUB-VARIABLE	Sound pressure p(t)				DEFINITION		Variation in pressure caused by a sound wave, relative to the ambient atmospheric pressure in a medium. It is measured as the root-mean-square (RMS) or instantaneous pressure of a sound wave. Sound Pressure Level (abbreviation: SPL, symbol: L_p) is the level in decibels for a time-averaged (RMS) sound pressure p with respect to a reference pressure p_0 is defined as $20 \log_{10}(p/p_0)$. The SI unit for pressure is the Pascal (Pa) and the underwater reference pressure is 1 μPa.	
	Resolution				Uncertainty		Sampling approach	References
	Spatial Horizontal	Spatial Vertical	Temporal	Timeliness	Measurement	Stability		
IDEAL	Array of multiple calibrated sensors regularly placed over entire assessed area (horizontally). Depends on frequency range of source: ranges over which sounds may be measured will vary.	Array of multiple calibrated sensors regularly placed over the entire assessed depths. Depends on frequency range of source: ranges over which sounds may be measured will vary.	24/7 recording but can be duty cycled. Depending on question or problem: day-night variations, weekly, monthly, lunar cycles, annually.	Depending on question or problem. - near-real time for monitoring for anthropogenic threats - monthly or each lunar cycle for long time series	Depends on hydrophone specifications (~ ± 1 dB)		Autonomous or cabled hydrophones recording at the minimum sampling rate to encompass the full spectrum of the source (i.e. for the full soundscape analysis, use highest sampling rate possible to avoid aliasing). From pressure p(t), can measure sound level, frequency content, temporal patterns, spatial extent, source occurrence.	Robinson, S.P.; Lepper, P. A. and Hazelwood, R.A. (2014) Good Practice Guide for Underwater Noise Measurement. Teddington, England, National Measurement Office, Marine Scotland, The Crown Estate, 95pp. (NPL Good Practice Guide No. 133). DOI: http://dx.doi.org/10.25607/OBP-21 Geel, N. C. F. van, Risch, D., & Wittich, A. (2022). A brief overview of current approaches for underwater sound analysis and reporting. Marine Pollution Bulletin, 178, 113610. doi:10.1016/j.marpolbul.2022.113610 Madhusudhana, S. et al. (2022). Choosing Equipment for Animal Bioacoustic Research. In: Erbe, C., Thomas, J.A. (eds) Exploring Animal Behavior Through Sound: Volume 1. Springer, Cham.

DESIRABLE	Array of several calibrated sensors regularly placed over most of the assessed area (horizontally). Depends on frequency range of source: ranges over which sounds may be measured will vary.	Array of several calibrated sensors regularly placed over most of the assessed depths. Depends on frequency range of source: ranges over which sounds may be measured will vary	Depends on question or problem: daily variations, weekly, monthly, lunar cycles, annually. Could be put on a duty cycle to increase longevity (e.g. recording 1 minute every 5 minutes) but should be representative of the site and sufficient to capture rare species.	Depending on question or problem: 6 months or less	Depends on hydrophone specifications (~ ± 1 dB)			https://doi.org/10.1007/978-3-030-97540-1_2 ISO (2017). 18405, " Underwater acoustics—Terminology" (International Organization for Standardization, Geneva, Switzerland), p. 51. Browning, E.; Gibb, R.; Glover-Kapfer, P. and Jones, K.E. (2017) Passive acoustic monitoring in ecology and conservation. Woking, UK, WWF-UK, 76pp. (WWF Conservation Technology Series 1(2)). DOI: http://dx.doi.org/10.25607/OBP-876 Mooney, T.A., Di Iorio, L., Lammers, M., Lin, T-H., Nedelec, S.L., Parsons, M., Radford, C., Urban, E. and Stanley, J. (2020) Listening forward: approaching marine biodiversity assessments using acoustic methods. Royal Society Open Science, 7:201287, 27pp. DOI: http://dx.doi.org/10.1098/rsos.201287 Ross, S.-J., O'Connell, D. P., Deichmann, J. L., Desjonquères, C., Gasc, A., Phillips, J. N., Sethi, S. S., Wood, C. M., & Burivalova, Z. (2023). Passive acoustic monitoring provides a fresh perspective on fundamental ecological questions. Functional Ecology, 37, 959–975.
MINIMUM	One calibrated sensor in the middle of the assessed area.	One calibrated sensor in the middle of the assessed area.	Depends on question or problem: daily variations, weekly, monthly, lunar cycles, annually. Could be put on a duty cycle	Depending on question or problem: 6 months	Depends on hydrophone specifications (~ ± 3 dB)			

			to increase longevity (e.g. recording 1 minute every 5 minutes) but should be representative of the site and sufficient to capture rare species.					https://doi.org/10.1111/1365-2435.14275 McKenna, M. F., Baumann-Pickering, S., Kok, A. C. M., Oestreich, W. K., Adams, J. D., Barkowski, J., … Hatch, L. T. (2021). Advancing the Interpretation of Shallow Water Marine Soundscapes. *Frontiers in Marine Science*, *08*, 719258. doi:10.3389/fmars.2021.719258 Marques, T. A., Thomas, L., Martin, S. W., Mellinger, D. K., Ward, J. A., Moretti, D. J., … Tyack, P. L. (2013). Estimating animal population density using passive acoustics. *Biological Reviews*, *88*(2), 287–309. doi:10.1111/brv.12001

EOV SUB-VARIABLE	Particle motion (displacement, velocity, acceleration)	**DEFINITION**	Sound **particle motion** refers to the oscillatory motion of particles in a medium caused by the propagation of a sound wave. This motion is distinct from the sound pressure, as it describes the physical movement of the particles in response to the wave's energy. Sound particle motion can be expressed in terms of displacement, velocity, and acceleration.

	Resolution				Uncertainty		Sampling approach	References
	Spatial Horizontal	Spatial Vertical	Temporal	Timeliness	Measurement	Stability		
IDEAL	Array of multiple calibrated sensors regularly placed over entire assessed area (horizontally). Depends on frequency range of source: ranges over which sounds may be measured will vary.	Array of multiple calibrated sensors regularly placed over the entire assessed depths. Depends on frequency range of source: ranges over which sounds may be measured will vary.	24/7 recording. Depending on question or problem: day-night variations, weekly, monthly, lunar cycles, annually.	Depending on question or problem. - near-real time for monitoring for anthropogenic threats - monthly or each lunar cycle for long time series	Depends on sensor specifications (~ ± 1 dB)		Autonomous or cabled particle motion sensor (e.g. vector sensor) recording at the minimum sampling rate to encompass the full spectrum of the source (i.e. for the full soundscape analysis, use highest sampling rate possible to avoid aliasing). By convention in underwater acoustics, the z axis is usually chosen to point vertically down from the sea surface, with x and y axes in the horizontal plane. From particle velocity and acceleration, can measure sound level, frequency content,	Nedelec, S. L., Campbell, J., Radford, A. N., Simpson, S. D., & Merchant, N. D. (2016). Particle motion: the missing link in underwater acoustic ecology. *Methods in Ecology and Evolution*, 7(7), 836–842. doi:10.1111/2041-210X.12544 Nedelec, S.L., Ainslie, M.A., Andersson, M.H., Cheong S-H., Halvorsen, M.B., Linné, M., Martin, B., Nöjd, A., Robinson, S., Simpson, S.D., Wang, L. and Ward, J. (2021) Best Practice Guide for Underwater Particle Motion Measurement for Biological Applications. Exeter, UK, University of Exeter for the IOGP Marine Sound and Life Joint Industry Programme, 89pp. & Appendices. DOI: http://dx.doi.org/10.25607/OBP-1726 ISO (2017). 18405, " Underwater acoustics—Terminology" (International Organization for Standardization, Geneva, Switzerland), p. 51.
DESIRABLE	Array of several calibrated sensors regularly placed over most of the assessed area (horizontally). Depends	Array of several calibrated sensors regularly placed over most of the assessed	Depends on question or problem: daily variations, weekly, monthly, lunar cycles, annually. Could be	Depending on question or problem: 6 months or less	Depends on sensor specifications (~ ± 1 dB)			

	on frequency range of source: ranges over which sounds may be measured will vary.	depths. Depends on frequency range of source: ranges over which sounds may be measured will vary	put on a duty cycle to increase longevity (e.g. recording 1 minute every 5 minutes) but should be representative of the site and sufficient to capture rare species.				temporal patterns, spatial extent, source occurrence.	
MINIMUM	One calibrated sensor in the middle of the assessed area.	One calibrated sensor in the middle of the assessed area.	Depends on question or problem: daily variations, weekly, monthly, lunar cycles, annually. Could be put on a duty cycle to increase longevity (e.g. recording 1 minute every 5 minutes) but should be representative of the	Depending on question or problem: 6 months	Depends on sensor specifications (~ ± 3 dB)			

			site and sufficient to capture rare species.					

Phenomenon 4	Acoustic indices of biodiversity, natural processes, or anthropogenic stressors. Note that the use of acoustic indices in underwater ecosystems is **debatable** due to the unique challenges and complexities of the underwater soundscape, which differ significantly from terrestrial environments. Most acoustic indices were developed and validated in terrestrial ecosystems and may not translate well to underwater environments. Combining acoustic indices with complementary approaches (e.g., machine learning) may help address some of their shortcomings.

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							unit for pressure is the Pascal (Pa) and the underwater reference pressure is 1 µPa.	
	Resolution				Uncertainty		Sampling approach	References
	Spatial Horizontal	Spatial Vertical	Temporal	Timeliness	Measurement	Stability		
IDEAL	Array of multiple sensors regularly placed over entire assessed area (horizontally). Depends on considered bandwidth: ranges over which sounds may be measured will vary.	Array of multiple sensors regularly placed over the entire assessed depths. Depends on considere d bandwidth : ranges over which sounds may be measured will vary.	24/7 recording. Depending on question or problem: day-night variations, weekly, monthly, lunar cycles, annually. Need also to consider natural temporal patterns (e.g. lunar cycle, day/night variation): analysing at least 48 h of acoustic data is a fundamental source of preliminary data to account for circadian and circatidal rhythms in marine ecosystems.	Depending on question or problem. Can be near real time (some sensors automatically calculate acoustic indices on the go).	While the sensor does not need calibration to measure some of the indices, the same models (set at the same sample rate) should ideally be used when comparing the indices of multiple sites etc. Similarly the same bandwidths should be used to compare indices.		Autonomous or cabled hydrophones and/or particle motion sensors, recording at the minimum sampling rate to encompass the full spectrum of the source (i.e. for the full soundscape analysis, use highest sampling rate possible to avoid aliasing). The bandwidth of interest to calculate the indices need to be standardised amongst sites and comparable studies. Sensors do not necessarily have to be calibrated (depending on index). Some sensors automatically calculate acoustic indices on the go.	Murilo Minello, Leandro Calado, Fabio C Xavier, Ecoacoustic indices in marine ecosystems: a review on recent developments, challenges, and future directions, ICES Journal of Marine Science, Volume 78, Issue 9, November 2021, Pages 3066–3074, https://doi.org/10.1093/icesjms/fsab193 Williams, B., Lamont, T. A. C., Chapuis, L., Harding, H. R., May, E. B., Prasetya, M. E., ... Simpson, S. D. (2022). Enhancing automated analysis of marine soundscapes using ecoacoustic indices and machine learning. Ecological Indicators, 140, 108986. doi:10.1016/j.ecolind.2022.108986 Bradfer-Lawrence, T., Desjonqueres, C., Eldridge, A., Johnston, A., & Metcalf, O. (2023).

DESIRABLE	Array of several sensors regularly placed over most of the assessed area (horizontally). Depends on considered bandwidth: ranges over which sounds may be measured will vary.	Array of several sensors regularly placed over most of the assessed depths.Depends on considere d bandwidth : ranges over which sounds may be measured will vary.	Depends on question or problem: daily variations, weekly, monthly, lunar cycles, annually. Need also to consider natural temporal patterns (e.g. lunar cycle, day/night variation):analysing at least 48 h of acoustic data is a fundamental source of preliminary data to account for circadian and circatidal rhythms in marine ecosystems. Could be put on a duty cycle to increase longevity (e.g. recording 1 minute every 5 minutes) but should	Depending on question or problem: 6 months or less	While the sensor does not need calibration to measure some of the indices, the same models (set at the same sample rate) should ideally be used when comparing the indices of multiple sites etc. Similarly the same bandwidths should be used to compare indices.			Using acoustic indices in ecology: Guidance on study design, analyses and interpretation. *Methods in Ecology and Evolution*. doi:10.1111/2041-210x.14194 Bradfer-Lawrence, T., Duthie, B., Abrahams, C., Adam, M., Barnett, R. J., Beeston, A., … Froidevaux, J. S. P. (2024). The Acoustic Index User's Guide: A practical manual for defining, generating and understanding current and future acoustic indices. Methods in Ecology and Evolution. doi:10.1111/2041-210x.14357 S.S. Sethi, N.S. Jones, B.D. Fulcher, L. Picinali, D.J. Clink, H. Klinck, C.D.L. Orme, P.H. Wrege, R.M. Ewers, Characterizing soundscapes across diverse ecosystems using a universal acoustic feature set, Proc. Natl. Acad. Sci. U.S.A. 117 (29) 17049-17055, https://doi.org/10.1073/pnas.2004702117 (2020).

			be representative of the site and sufficient to capture rare species.					
MINIMUM	One sensor in the middle of the assessed area.	One sensor in the middle of the assessed area.	Depends on question or problem: daily variations, weekly, monthly, lunar cycles, annually. Need also to consider natural temporal patterns (e.g. lunar cycle, day/night variation): analysing at least 48 h of acoustic data is a fundamental source of preliminary data to account for circadian and circatidal rhythms in marine ecosystems. Could be put on a duty cycle to increase	Depending on question or problem: 6 months	While the sensor does not need calibration to measure some of the indices, the same models (set at the same sample rate) should ideally be used when comparing the indices of multiple sites etc. Similarly the same bandwidths should be used to compare indices.			

			longevity (e.g. recording 1 minute every 5 minutes) but should be representative of the site and sufficient to capture rare species.					

4. Observing approach, platforms and technologies

This table provides examples of approaches and technologies used to collect this EOV to help observe priority phenomena

APPROACH / PLATFORM	Acoustic autonomous recording unit (ARU)	Cabled sensor	Bottom mounted system
EOV SUB-VARIABLE(S) MEASURED	pressure p(t),	pressure p(t),	pressure p(t),

	particle velocity u(t) and/or particle acceleration a(t)	particle velocity u(t) and/or particle acceleration a(t)	particle velocity u(t) and/or particle acceleration a(t)
TECHNIQUE / SENSOR TYPE	**ARU** are self-contained audio recording device	Cabled **hydrophone** or **vector sensor**	In case of the bottom mounted systems, typically, an **ARU** is deployed on the sea bottom. This system will use deployment and recovery equipment that can include anchor, anchor line, acoustic releaser and flotation(s). For the shallow deployments, can be a diver who can release the measuring system from the anchor and let it surface owing to the flotation attached.
SUGGESTED METHODS AND BEST PRACTICES	Each commercially-available ARU will have its own manual for best practises and recommendations on deployment, maintenance and calibration. See Ocean Sound EOV implementation Plan Also see Metcalf et al. (2023) Good practice guidelines for long-term ecoacoustic monitoring in the UK. The UK Acoustics Network.	See Ocean Sound EOV implementation Plan Hydrophones: Vukadin, P., Miralles, R. and le Courtois, F. (2018) QuietMED D3.5 Best practice guidelines on continuous underwater noise measurement (criterion D11C2). quietMED, 35pp. DOI: https://doi.org/10.25607/OBP-1943 Corzilius, B. (1996). Hydrophone Usage and Deployment Collected Methods and Sources. Cornell Bioacoustics Research Program Robinson, S.P.; Lepper, P. A. and Hazelwood, R.A. (2014) Good Practice Guide for Underwater Noise Measurement. Teddington, England, National Measurement Office, Marine Scotland, The Crown Estate, 95pp. (NPL Good Practice Guide No. 133). DOI: http://dx.doi.org/10.25607/OBP-21 Calibration of hydrophones: International Electrotechnical Commission (2019) IEC 60565-2:2019 Underwater acoustics - Hydrophones - Calibration of hydrophones - Part 2:	The anchor weight and shape should be adjusted to the bottom type and expected strain to the system (e.g. currents or waves in case the surface buoy is used). If the bottom is mud, small and heavy anchor (e.g. lead) can gradually be buried into the bottom together with the measuring system thus compromising the part of the recording period and also causing problems with recovery. Due to the close proximity to the hydrophone, deployment gear can generate unwanted sound. This is especially true for the fixtures of the anchor rope to the anchor, acoustic releaser and system container, which are usually stainless steel shackles and eyes. Metal fixtures should be avoided or somehow isolated (e.g. rubber sleve) from the direct contact that can produce sound. Biofouling can also be an issue for longer deployments on some locations. See Ocean Sound EOV implementation Plan Also see:

		Procedures for low frequency pressure calibration. Edition 1. Geneva, Switzerland, International Electrotechnical Commission (IEC), 108pp. International Electrotechnical Commission (2024)IEC 63305:2024 Underwater acoustics – Calibration of acoustic wave vector receivers in the frequency range 5 Hz to 10 kHz Geneva, Switzerland, International Electrotechnical Commission (IEC). American National Standards Institute, Inc. (2012) ANSI/ASA S1.20-2012 Procedures for Calibration of Underwater Electroacoustic Transducers. Melville, NY, American National Standards Institute, Inc. (ANSI). Available: https://webstore.ansi.org/standards/asa/ansiasas1202012 Vector sensors: Nedelec, S.L., Ainslie, M.A., Andersson, M.H., Cheong S-H., Halvorsen, M.B., Linné, M., Martin, B., Nöjd, A., Robinson, S., Simpson, S.D., Wang, L. and Ward, J. (2021) Best Practice Guide for Underwater Particle Motion Measurement for Biological Applications. Exeter, UK, University of Exeter for the IOGP Marine Sound and Life Joint Industry Programme, 89pp. & Appendices. DOI: http://dx.doi.org/10.25607/OBP-1726	Vukadin, P., Miralles, R. and le Courtois, F. (2018) QuietMED D3.5 Best practice guidelines on continuous underwater noise measurement (criterion D11C2). quietMED, 35pp. DOI: https://doi.org/10.25607/OBP-1943
SUPPORTING VARIABLES MEASURED	ARUs sometimes also encompass other sensors that measure subsurface		Bottom mounted system can host a whole variety of other sensors to measure additional supporting variables like: sea

	temperature, subsurface salinity, ocean bottom pressure, acoustic indices		state, sea ice, subsurface temperature, subsurface salinity, subsurface currents, ocean bottom pressure, bathymetry, sediment

APPROACH / PLATFORM	Drifting system	Surface system	Land-based system
EOV SUB-VARIABLE(S) MEASURED	pressure p(t)	pressure p(t), particle velocity u(t) and/or particle acceleration a(t)	pressure p(t), particle velocity u(t) and/or particle acceleration a(t)
TECHNIQUE / SENSOR TYPE	The most usual usage of the **drifter system** for continuous underwater noise measuring is the measurement of the underwater sound in strong current or tidal flows that would cause high levels of flow noise if the hydrophone of the system was stationary. The deployment and recovery of the drifter systems is relatively simple and inexpensive. However, it requires more complicated processing and result analyses due to its mobility.	In case of **surface-based systems**, a cabled **hydrophone** or **vector sensor** is deployed from a surface platform, most commonly a vessel.	In a **land-based system**, the recording system is deployed on the land (e.g. seashore). The land-based system's main advantages are: real time operation, no memory and power issues, deployment period virtually indefinite, low chance of equipment being stolen.
SUGGESTED METHODS AND BEST PRACTICES	As the drifter is constantly moving, its exact position should be known in order to correctly process collected underwater noise data. Thus the GPS receiver on the buoy is the standard additional sensor and GPS position data are continuously logged.	Surface vessels can be (and in reality certainly are) the source of unwanted sound (platform self-noise) which is received and recorded by the acoustic sensor. All machinery and mechanical equipment on the vessel, as well as crew's activity onboard, vibrates the vessel's hull which produces underwater sound which along with cavitation noise	The sea bottom deployed hydrophone and long cables include potential risk of accidental damage by humans, mostly fishing activities. Biofouling of the hydrophone can also be an issue for longer deployments on some locations.

	The drifter systems may suffer from potential damage or theft. Unattended, clearly visible and marked buoy can be vandalized or stolen. See Ocean Sound EOV implementation Plan Also see: Lillis, A., Caruso, F., Mooney, T. A., Llopiz, J., Bohnenstiehl, D., & Eggleston, D. B. (2018). Drifting hydrophones as an ecologically meaningful approach to underwater soundscape measurement in coastal benthic habitats. *Journal of Ecoacoustics*, 2(1), STBDH1. doi:10.22261/jea.stbdh1 Vukadin, P., Miralles, R. and le Courtois, F. (2018) QuietMED D3.5 Best practice guidelines on continuous underwater noise measurement (criterion D11C2). quietMED, 35pp. DOI: https://doi.org/10.25607/OBP-1943	from the propeller can be picked up by the sensor. Also, the hydrophone's cable and anchor chain strumming the vessel's hull and vessel splashing on the sea surface produces underwater sound. Finally, any movement of the sensor caused by vessel movement (e.g. waves) to which it is connected, or pendulum like movement of the suspended sensor will produce flow noise. Avoiding platform self-noise is not an easy, sometimes impossible task. The most commonly used strategy is to suspend the sensor not directly from the vessel but from the buoy at some distance from the vessel. The sensor cable is connected from the sensor to the buoy and then horizontally to the vessel. In that way cable strum and the effect of vessel's movement can be reduced. For these reasons, surface-based underwater sound measuring systems are not recommended for quality sound measurements, unless the level of the platform self-noise is assessed and considered acceptable for the purpose of the measurement. See Ocean Sound EOV implementation Plan	See Ocean Sound EOV implementation Plan
SUPPORTING VARIABLES MEASURED	Bottom mounted system can host a whole variety of other sensors to measure additional supporting variables like: sea state, subsurface temperature, subsurface salinity, subsurface currents	A range of other sensors to measure additional supporting variables can be deployed from the platform, like: sea state, sea ice, subsurface temperature, subsurface salinity, subsurface currents, ocean bottom pressure, bathymetry, sediment	A range of other sensors to measure additional supporting variables can be deployed along with the acoustic sensor, like: sea state, sea ice, subsurface temperature, subsurface salinity, subsurface currents, ocean bottom pressure, bathymetry, sediment

APPROACH / PLATFORM	Animal tags	Roaming systems: glider, AUV, ROV, submersible	Towed system
EOV SUB-VARIABLE(S) MEASURED	pressure p(t)	pressure p(t)	pressure p(t)
TECHNIQUE / SENSOR TYPE	Tags equipped with hydrophones can provide detailed information about both animal behavior and sound exposure. Hydrophones pick up both the sounds to which the animals are exposed and the sounds that they produce. Tags store acoustic data internally. Some tags use transmitters (radio, ultrasonic or satellite) to relay data back to the researchers via computer technology and enable tracking and observations of the animal when it surfaces. The data can also be retrieved when tags come off and are recovered. Tagging technologies are rapidly advancing as electronics become smaller.	Mobile autonomous platforms, including surface drifters, profiling floats, electric gliders, and surface autonomous vehicles can all carry acoustic sensors. These platforms have the capability to range over tens to thousands of kilometers, and often the platform is quiet enough to allow excellent passive acoustic monitoring, particularly at higher frequencies. These systems typically record acoustic data for post-analysis and often employ some means of on-board data processing to support real-time detection and classification of marine species and reporting via satellite communications link.	**Towed arrays** typically permit localisation of sound sources up to several times the aperture of the array. Assembled with sensors aimed at detecting acoustic signals, and vibrations in general, in water, towed arrays are designed to minimize unwanted hydrodynamic noise.
SUGGESTED METHODS AND BEST PRACTICES	See Ocean Sound EOV implementation Plan Also, see: Johnson, Mark & Aguilar de Soto, Natacha & Madsen, Peter. (2009). Studying the behaviour and sensory ecology of marine mammals using acoustic recording tags: A review. Marine Ecology-progress Series - MAR ECOL-PROGR SER. 395. 55-73. 10.3354/meps08255.	See Ocean Sound EOV implementation Plan Also, see: Cauchy, P., Heywood, K. J., Merchant, N. D., Risch, D., Queste, B. Y., and Testor, P. (2023). Gliders for passive acoustic monitoring of the oceanic environment. *Frontiers Remote Sens* 4, 1106533. doi: 10.3389/frsen.2023.1106533	See Ocean Sound EOV implementation Plan Also, see: M. Lasky, R. D. Doolittle, B. D. Simmons and S. G. Lemon, "Recent progress in towed hydrophone array research," in IEEE Journal of Oceanic Engineering, vol. 29, no. 2, pp. 374-387, April 2004, doi: 10.1109/JOE.2004.829792.
SUPPORTING VARIABLES MEASURED	Acoustic recording tags can contain a variety of other sensors for recording marine animal behavior. Time-depth	Subsurface temperature, subsurface salinity, pH, subsurface currents, chlorophyll fluorescence, optical	Time, depth, GPS, temperature, tow cable tension and length

	recorders provide information about dive times and depths, as well as time spent at the surface. Accelerometers and compasses measure the animal's orientation and heading. Video cameras record underwater images and provide information about the animal's surroundings. Global Positioning System (GPS) receivers provide geographic position information when the animals are on the surface. Some tags store the data internally. Tags can also include other sensors like: subsurface temperature, subsurface salinity, ocean bottom pressure.	backscatter, bottom depth, acoustic backscatter, dissolved oxygen, nitrate, plankton abundance, turbidity, animal telemetry	

5. Data and information management

Access to data and information is at the core of an ocean observing system. This section provides essential information on how to contribute data to the GOOS

The GOOS approach to data management is aligned with open data and FAIR (Findable, Accessible, Interoperable, Reusable) practices. All EOV data and information is valuable, thus effective data management practices are essential to ensure it remains accessible and (re)usable for future generations.

The Ocean Sound EOV emphasises the need for routinely collected, standardised acoustic data to support long-term observations and predictions, as well as scientific research. All recordings must be accompanied by standardised metadata, including calibration data (e.g., hydrophone sensitivity by frequency and directionality), and converted into SI units.

Please follow these practices carefully, as BioEco EOV data FAIRness relies on compliance with these guidelines.

Before proceeding, please note these important points:

1. As a **minimum**, you must ensure information describing your EOV data (i.e. metadata) are visible in the Ocean Data and Information System (ODIS)[1]. Regardless of where the actual data is stored, evidence of its existence must be findable within ODIS.
2. BioEco EOV data is successfully managed if it is discoverable in the **GOOS BioEco Portal.** The BioEco Portal is the central point of access and coordination of BioEco EOV observing programmes. Data visible in ODIS will automatically be visible in the BioEco Portal and vice versa. **Due to the high volume of acoustic data, it is not yet feasible to store these directly in OBIS, the main GOOS repository for biology and ecosystem EOVs. Instead, the Ocean Sound EOV proposes archiving acoustic time series in national and institutional data centers, which would be linked to OBIS via metadata.**

The main data management steps are as follow:

1. Become discoverable: ensure the data producers (e.g., organisation, programme, project, etc.) and datasets are visible in ODIS
2. Prepare the required metadata about the data producer and the datasets
3. Publish EOV data at the international systems that already serve as potential nodes (**see below**).
4. Verify discoverability in ODIS

Not all steps may be relevant for you, but **Step 1 is the minimum required** to ensure your data contributes to EOVs. .

[1] ODIS, part of IOC-UNESCO's International Oceanographic Data and Information Exchange (IODE), is a global federation of data systems sharing interoperable (meta)data about holdings, services, and other resources to enhance cross-domain data accessibility.

TO CONTRIBUTE DATA AND METADATA TO THE GLOBAL OBSERVING SYSTEM, PLEASE GO TO: https://iobis.github.io/eov-data-management/

Help Resources

- EOV Metadata Submission tool: https://eovmetadata.obis.org/

International systems already serve as potential nodes in a distributed data network, including:

- **Australia**: AODN and the Australian Antarctic Division Data Centre
- **Canada**: Ocean Networks Canada
- **European Union**: Projects like INTAROS
- **Germany**: The OPUS portal by the Alfred Wegener Institute
- **Norway**: Lofoten Ocean Observatory and the Norwegian Marine Data Center
- **United Kingdom**: The MEDIN data portal
- **United States**: NOAA NCEI, SanctSound, ADEON, NOAA map portal, Integrated Ocean Observing System, Aloha Cabled Observatory, MBARI Cabled Observatory, Ocean Observatories Initiative, Thetis
- **Globally**: The IQOE Acoustic Data Portal, PANGEA

This distributed model leverages existing national infrastructure, with data feeding into international systems, facilitating global coordination while managing large and complex datasets efficiently.

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ODIS

- General help https://book.odis.org/index.html
- Connecting to ODIS https://book.odis.org/gettingStarted.html
- ODIS Catalogue of Sources: https://catalogue.odis.org/
- Ocean Info Hub: https://oceaninfohub.org/
- Schema.org framework https://schema.org/

GOOS BioEco Portal

- Documentation https://iobis.github.io/bioeco-docs/
- Access https://bioeco.goosocean.org/

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Integrated EOV products and visualisations

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Acronyms and Abbreviations

ARU: Autonomous Recording Unit

CBD: Convention on Biological Diversity

EBV: Essential Biodiversity Variables

ECV: Essential Climate Variables

EOV: Essential Ocean Variables

GCOS: Global Climate Observing System

GEO BON: Group on Earth Observations Biodiversity Observation Network

GOOS: Global Ocean Observing System

IOCCP: International Ocean Carbon Coordination Project

MBON: Marine Biodiversity Observation Network

OBIS: Ocean Biodiversity Information System

ODIS: Ocean Data Information System

OCG: Observation Coordination Group

OOPC:Ocean Observations Physics and Climate Panel

SDG: Sustainable Development Goals

Glossary of terms

Acoustic indices: mathematical or statistical measures that capture specific attributes of soundscapes, such as intensity, diversity, periodicity, or dominance, and are commonly used to assess biological, physical, and anthropogenic contributions to the acoustic environment. Acoustic indices are widely used in fields such as bioacoustics, ecology, conservation, and environmental monitoring to assess biodiversity, monitor ecosystem health, measure anthropogenic impact and identify temporal and spatial patterns of ocean processes. The use of acoustic indices in underwater ecosystems is debatable due to the unique challenges and complexities of the underwater soundscape, which differ significantly from terrestrial environments. Most acoustic indices were developed and validated in terrestrial ecosystems and may not translate well to underwater environments. Combining acoustic indices with complementary approaches (e.g., machine learning) may help address some of their shortcomings.

Autonomous recording unit (ARU) is a self-contained audio recording device that is deployed in marine or terrestrial environments for acoustical monitoring. It typically contains the sensor (hydrophone and/or vector sensor), preamplifier, data acquisition system, processor, memory storage and battery in a water-proof enclosure. All system parts except the **hydrophone** are placed into the waterproof pressure resistant housing (container) to ensure their functionality under the water. The hydrophone is either packed within the container or separately but close to the container to which it is connected with a short cable. The power is supplied from battery pack also placed inside the container. The system stores (records) the acoustic data for the period of its deployment. After it is recovered from the bottom, data are downloaded to the external computer for final storage and processing. Additionally, some systems are designed to transmit measured data to the external computer via some intermediate device. This is the most usually the buoy deployed (anchored) on the sea surface above the sea bottom mounted system.

Derived products: outputs calculated from the EOV and sub-variables, often in combination with the supporting variables, that contribute to evaluating change in phenomena. For example, evaporation can be determined from sea surface temperature measurements; air-sea fluxes of CO2 can be derived from inorganic carbon EOV; fish stock productivity can be determined from fish abundance.

Drifter system: the hydrophone is deployed suspended from the surface buoy that drifts freely driven by wind, waves, current or tide. All system parts except the hydrophone are usually placed inside the buoy. The hydrophone is suspended from the surface buoy at the desired depth and connected to the buoy with a cable. However, configuration with all system parts within waterproof pressure housing which is also suspended from the buoy is also possible. The most important feature of the drifter design is the positioning of the hydrophone to be stationary to the body of the water moving horizontally. The drogue (e.g. sea anchor, “underwater parachute”) is used for that purpose. The drogue also decouples the motion of the surface buoy from the hydrophone.

Hydrophone: an electroacoustic transducer that converts variations in the underwater pressure caused by underwater acoustic sources to the variations in electrical voltage on its output. Typical specifications are sensitivity, frequency range (bandwidth), linearity, directivity pattern, maximum operating depth (or pressure), self-noise, operating temperature range and impedance.

Indicators: An indicator can be defined as a ‘measure based on verifiable data that conveys information about more than just itself’. This means that indicators are purpose dependent - the interpretation or meaning given to the data depends on the purpose or issue of concern. (BIP definition)

Landed-based system: The recording system is deployed on the land (e.g. seashore). All system parts except the sensor are located on land. The sensor (**hydrophone** or **vector sensor**) is placed on the seabed or suspended in the water column and connected to the rest of the system equipment ashore with the long cable. The land-based system’s main advantages are: real time operation, no memory and power issues, deployment period virtually indefinite, low chance of equipment being stolen.

Measurement Uncertainty – the parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand (GUM)[1]. It includes all contributions to the uncertainty, expressed in units of 2 standard deviations, unless stated otherwise

Phenomena: properties (e.g., of a species such as distribution), processes (e.g., of the ocean such as surface ocean heat flux), or events (e.g., such as algal blooms) that have distinct spatial and temporal scales, and when observed, inform evaluations of ocean state and ocean change

Sound particle acceleration a(t): the rate of change of particle velocity with respect to time. Units: meters per second squared (m/s^2).

Sound particle displacement □(t): the back-and-forth movement of particles in the medium caused by the sound wave. Units: meters (m)

Sound particle motion: refers to the oscillatory motion of particles in a medium caused by the propagation of a sound wave. This motion is distinct from the sound pressure, as it describes the physical movement of the particles in response to the wave's energy. Sound particle motion can be expressed in terms of **displacement**, **velocity**, and **acceleration**.

Sound particle velocity u(t) :the rate of change of particle displacement with respect to time. Units: meters per seconds (m/s)

Sound pressure p(t): variation in pressure caused by a sound wave, relative to the ambient atmospheric pressure in a medium. It is measured as the root-mean-square (RMS) or instantaneous pressure of a sound wave. Sound Pressure Level (abbreviation: SPL, symbol: L_p) is the level in decibels for a time-averaged (RMS) sound pressure p with respect to a reference pressure p_0 is defined as $20 \log_{10}(p/p_0)$. The SI unit for pressure is the Pascal (Pa) and the underwater reference pressure is 1 μPa.

Stability – The change in bias over time. Stability is quoted per decade.

Supporting variables: other measurements that are useful to provide scale or context to the sub-variables of the EOV (e.g., pressure measurements to provide information on the depth at which subsurface currents are estimated, sea temperature to understand dissolved inorganic carbon, water turbidity to support estimations of hard coral cover).

Sub-variables: key measurements that are used to estimate the EOV (e.g., counts of individuals to provide an estimate of species abundance (such as fish, mammals, seabirds or turtles), partial pressure of carbon dioxide (pCO_2)to estimate ocean inorganic carbon, or wave height to estimate sea state).
Surface-based systems: a cabled **hydrophone** or **vector sensor** is deployed from a surface platform, most commonly a vessel. The vessel can be free floating, or more usually, anchored. All system parts except the sensor are usually placed aboard the vessel, while the sensor is suspended from the vessel at the desired depth and connected to the equipment aboard with a cable.

Timeliness - The time expectation for availability of data measured from the data acquisition time.

Towed arrays: have anywhere from two to hundreds of hydrophones, and are typically towed behind a vessel on a cable tens to thousands of meters long. Arrays typically permit localization of sound sources up to several times the aperture of the array. Assembled with sensors aimed at detecting acoustic signals, and vibrations in general, in water, towed arrays are designed to minimize unwanted hydrodynamic noise.

Vector sensor: specialised sensor used to measure both the magnitude and direction of sound in a medium. Unlike traditional acoustic sensors, which typically only measure sound pressure, a vector sensor captures information about the particle motion associated with a sound wave, including its displacement, velocity, and acceleration.

Appendix - Additional information

A1. Applications

This table provides examples of applications of this EOV, including contribution to other essential variable frameworks, multilateral environmental agreements, and contribution to indicators and GOOS applications

EOV		Ocean Sound
CORRESPONDING ESSENTIAL VARIABLES	ECV	Marine Habitats, Precipitation, Lightning, Surface Wind Speed, Sea Ice, Sea State, Ice Sheets and Ice Shelves
	EBV	Community composition, Ecosystem functioning, Ecosystem structure, Species populations, Species traits
GLOBAL INDICATORS EOV CAN CONTRIBUTE	**SDG**	3, 9, 13, 14
	CBD GBF	Goal A: Protect and restore Goal B: Prosper with nature Target 1: Plan and manage all areas to reduce biodiversity loss Target 3: Conserve 30% of land, water and seas Target 7: Reduce pollution to levels that are not harmful to biodiversity Target 11: Restore, maintain and enhance nature's contributions to people Target 20: Strengthen capacity-building, technology transfer, and scientific and technical cooperation for biodiversity Target 21: Ensure that knowledge is available and accessible to guide biodiversity action
GOOS APPLICATIONS		Climate Change, Ocean Health, Operational Services

A2. Readiness level assessment

Examples at Readiness level 9

- Comprehensive Test Ban Treaty Organisation Ocean Acoustic Measurements (https://www.ctbto.org/verification-regime/monitoring-technologies-how-they-work/hydroacoustic- monitoring/)
- ALOHA Cabled Observatory (http://aco-ssds.soest.hawaii.edu/) Examples at Readiness level 8
- US NOAA noise reference stations (https://www.pmel.noaa.gov/acoustics/ocean-noise-reference.html)
- DONET (https://www.jamstec.go.jp/donet/e/index.html) Examples at Readiness level 6-7
- BIAS (https:\\biasproject.wordpress.com): readiness level 7 but project lasted one year and is completed
- OHA-SIS-BIO (https://www-iuem.univ-brest.fr/lgo/fr/Observation/marine/hauturiere) readiness level 6-7

Essential Ocean Variable Specification Sheet

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